APPENDIX G

TECHNICAL REPORT ON

EARTH

BP CHERRY POINT REFINERY COGENERATION PROJECT

Prepared for:

BP West Coast Products, LLC

Submitted by:

Golder Associates Inc.

June, 2002 013-1421.510

EXECUTIVE SUMMARY

This Technical Report on Earth was prepared to address the issues associated with earth as outlined in the Potential Site Study (PSS) – BP Cherry Point Cogeneration Project issued by the Washington State Energy Facility Site Evaluation Council (EFSEC) by Shapiro and Associates, Inc. (September 28, 2001). The BP Cherry Point Cogeneration Project (Cogeneration Project) is a proposed 720-megawatt cogeneration facility.

The proposed Cogeneration site is located in western Whatcom County, Washington, adjacent to the existing BP Cherry Point Refinery (Refinery) and within Township 39N, Range 1E, northwest quadrant of Section 8. A vicinity map is provided in Figure 1.0-1 that depicts the location of the Cogeneration Project and surrounding areas. The nearest towns are the City of Ferndale located approximately 6 miles to the southeast and the City of Blaine located approximately 7 miles to the north. The nearest salt-water body is the Strait of Georgia (at Cherry Point) located approximately 2 miles to the southwest. Point Whitehorn and Birch Bay both form prominent shoreline features along the Strait of Georgia and are located approximately 3 miles west and 2 miles northwest, respectively. The nearest significant freshwater is Lake Terrell located approximately 2 miles to the southeast, and Terrell Creek, which drains Terrell Lake and passes within 1 mile to the east and 0.5 miles to the north of the proposed Cogeneration Project.

TABLE OF CONTENTS Page No.

LIST OF TABLES

LIST OF FIGURES

ATTACHMENTS

LIST OF ACRONYMS

BMP	Best Management Practice
Cogeneration Project	BP Cherry Point Cogeneration Project
EFSEC	Washington State Energy Facility Site Evaluation Council
g	Gravity
M	Magnitude (approximately equivalent to the Richter Scale)
amsl	above mean sea level
MMI	Modified Mercalli Earthquake Intensity
PGA	Peak Ground Acceleration
PSS	Potential Site Study
UBC	Uniform Building Code

TERMS AND DEFINITIONS

Aftershocks	An earthquake that follows a larger earthquake and originates at or near the focus of the latter.
Alluvial	Pertaining to or composed of alluvium, or deposited by a stream or running water.
Alluvium	A general term for dentrital deposits made by streams on riverbeds, floodplains, and alluvial fans.
Anticline	A fold, generally convex upward, whose core contains the statigraphically older rocks
Basalt	A dark colored rock igneous rock, commonly extrusive, composed primarily of calcite plagioclase and pyroxene
Bedrock	A solid rock that underlies gravel, soil, or other superficial material.
Drift deposit	A general term applied to unconsolidated geologic materials that were transported from one place and deposited in another.
Fault	A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.
Fold	A bend or plictation in the bending, foliation, cleavage, or other planer features in rocks.
Formation	A body of rock strata that consists dominantly of a certain lithologic type or combinations of types.
Groundwater	That part of subsurface water that is in the zone of saturation.
Hydraulic Conductivity	The rate of flow of water in gallons per day through a cross-section of one foot square under a unit hydraulic gradient.
Intensity	Measure of effects of earthquake waves on human beings, structures, and earth's surface at a particular place.
Interbed	A bed, typically thin, of one type of rock material occurring between or alternating with beds of another kind.
Interstade	A warmer substage of a glacial stage, marked by a temporary retreat of the glacier.
Isopach Map	A map that shows the thickness of a bed, formation, sill or other tabular body throughout a geographic area by means of isopachs at regular intervals.

Isoseismal	Points of equal earthquake intensity
Liquefaction	The transformation of a soil from a solid to a liquid state as the result of increased pore pressure.
Loess	Deposits of wind-borne dust.
Magnitude	Measure of total energy released by an earthquake.
Mass-Wasting	A general term for the downslope movement of soil and rock material under the direct influence of gravity.
Piezometer	A basic device for the measurement of hydraulic head at a given point.
Pyroclastic	Pertaining to clastic rock formed by volcanic explosion or aerial expulsion from a volcanic vent.
Sedimentary	Pertaining to or containing sediment, or formed by its deposition.
Seismic	Pertaining to an earthquake or earth vibration, including those that are artificially induced
Seismicity	The likelihood of an area being subjected to earthquakes.
Siltstone	An indurated silt having the texture and composition of shale but lacking the fine lamination or fissility.
Stade	A colder substage of a glaciation, marked by a readvance of the glacier.
Static Water Level	Water levels at equilibrium or steady state condition
Subduction Zone	A long, narrow belt in which in which one lithospheric plate descends relative to another.
Syncline	A fold, generally concave upward, whose core contains statigraphically younger rocks
Tectonic	Pertaining to the forces involved in, or the resulting structures of tectonics.
Tephra	Pyroclastic materials that fly from an erupting volcano through the air before cooling, and range in size from fine dust to massive blocks.
Tsunami	A large wave in the ocean generated at the time of an earthquake; sometimes called a seismic sea wave.
Volcaniclastic	Pertaining to a clastic rock containing volcano material in whatever proportion, and without regard to its origin or environment.
Volcanism	The process by which magma and its associated gas rise into the crust and are extruded onto the earth's surface and into the atmosphere.

1. TOPOGRAPHY

The proposed Cogeneration Project site is situated at an elevation of approximately 120 feet above mean sea level (amsl). The land surrounding the proposed Cogeneration Project is relatively flat and owned by BP for at least 0.5 miles in all directions. The closest resident is about 0.75 miles north from the proposed Cogeneration Project. Prior to construction of the Refinery in 1969 the land was used for agriculture. Land north of Grandview Road and north of the proposed Cogeneration Project is used by BP for habitat enhancement and for buffering industrial operations. Terrell Creek is located within BP's habitat enhancement area north of the Cogeneration site. The creek runs through a shallow, narrow depression, which is 10 to 15 feet lower in elevation than the surrounding area. Nearby industries other than the Refinery include Chemco, about 0.75 miles east, at an elevation of about 160 feet amsl, and Praxair, about 1.0 miles south of the proposed Cogeneration Project, at a similar elevation.

The proposed Cogeneration Project site is depicted on a topographic map in Figure 1.0-2 and in detail in Figure 1.0-3. As shown on the figures the topography slopes toward the northwest. Existing slopes range from 0.5% to 1%. Therefore, no significant topographic modifications will be required to prepare the site. No modifications to drainage patterns will occur as described in Appendix F: Technical Report on Water.

2. GEOLOGY

2.1 Regional Geology

2.1.1 Physiography

The proposed Cogeneration Project site lies entirely within the northern portion of the Puget Trough section of the Pacific Border physiographic province (Fenneman, 1912). The proposed Cogeneration Project site is situated in that part of the Puget Trough known as the Whatcom Basin (or Fraser Lowland). The Puget Trough is bounded on the east by the Cascade Range, on the west by the Vancouver Island Ranges and Olympic Mountains, and on the north by the Coast Mountains (British Columbia). Figure 2.1-1 depicts the regional physiography surrounding the proposed Cogeneration Project site.

The Whatcom Basin is characterized by hummocky glaciomarine drift plains; nearly level glaciofluvial terraces that have large bogs; and rolling drift-capped uplands overlooking the broad flood plain of the Nooksack River (Goldin, 1992).

Whatcom Basin, Fraser Lowland, and northern Puget Lowland refer to the same general physiographic areas and are used interchangeably in this report.

2.1.2 Generalized Geologic History

It is widely thought that approximately 200 million years ago, the supercontinent, "Pangaea," began to break up, opening the Atlantic Ocean along a mid-ocean ridge. As a result, the North American continent began moving westward causing the Oceanic Crust to subside beneath the western margin of the North American plate. During this time, subcontinents were accreted to the western margin of North America forming various exotic terranes. Much of the north Cascade Range and Vancouver Island are composed of these terranes.

At the beginning of the Eocene (approximately 57 million years ago), the region was covered by a vast alluvial floodplain with a vegetative cover of lowland semitropical rain forest. This resulted in the deposition of the Chuckanut Formation within a faulted down-dropped basin. This depositional environment ended with displacement along the Straight Creek fault (approximately 60 miles to the west) and the uplift of the lowland basins. Around 42 mya, regional tectonics changed from transtensional to transpressional, initiating folding and thrusting of the Chuckanut Formation (Roberts, 1999). The sandstones, conglomerates, shales, and coal deposits of the Chuckanut Formation are exposed in the Chuckanut Mountains along the southern margin of the Whatcom Basin immediately south of Bellingham (Easterbrook, 1976).

The region experienced many episodes Cordilleran ice sheet advancement during the Pleistocene (Armstrong and others, 1965; Easterbrook and others, 1967; Easterbrook, 1994). The Puget Lowland geologic-climate succession (after Easterbrook, 1963 and 1994) from youngest to oldest is as follows:

- Fraser Glaciation
  - Sumas Stade
  - Everson Interstade
  - Vashon Stade
  - Evans Creek Stade
- Olympia Interglaciation
- Salmon Springs Glaciation
- Puyallup Interglaciation
- Stuck Glaciation
- Alderton Interglaciation
- Orting Glaciation

The geologic-climate units include two major units, the Olympia Interglaciation and the Fraser Glaciation. The Fraser Glaciation represents the most important in terms of the surficial deposits in the area of the proposed Cogeneration Project site.

The Olympia Interglaciation started at least 36,000 years ago and continued until the advance of the Cordilleran ice sheet during the Fraser Glaciation into the Fraser lowland about 24,500 years ago. The ice sheet originated in the mountains of British Columbia, mostly in the Coast Mountains and partly on Vancouver Island, and advanced southward into the Puget Lowland as the Puget lobe. The Evans Creek stade represents the early stage of the Fraser Glaciation where large alpine glaciers reached their maximum extent and deposited drift in the mountains of western Washington. These alpine glaciers were already in recession at the time of the advancement of the Cordilleran ice sheet into the Puget Lowland. The Vashon Stade began with the advancement of the Cordilleran ice sheet into the lowlands of southwestern British Columbia and northwestern Washington. The ice sheet entered the Fraser Lowland about 24,500 years ago and reached its maximum extent about 15 miles south of Olympia about 15,000 years ago. The ice retreated from the southern Puget Lowland about 13,500 years ago and permitted marine water to enter the area. Marine water occupied the Strait of Georgia area and adjoining lowlands about 13,000 years ago. (Armstrong and others, 1965).

The Everson interstade is characterized by the deposition of glaciomarine, marine, and related deposits in the coastal lowlands of southwestern British Columbia and northwestern Washington during the retreat of the Vashon ice (Armstrong and others, 1965). The Everson interstade occurred from about 13,000 to 10,000 years ago. During the late stage of the recession, when the ice was no more than a few hundred feet thick, marine waters entered the area, floating the ice. Glaciomarine drift was deposited beneath the floating ice. These deposits are known as the Kulshan glaciomarine drift. Several hundred feet of land emergence then occurred during which fluvial and lacustrine sediments were deposited. These deposits are known as the Deming sand. A readvance of ice into northern Washington coincided with the submergence of the lowland and the entry of marine water with floating ice. As a result, a second glaciomarine drift was deposited in places 400 to 600 feet above sea level. These deposits are known as the Bellingham glaciomarine drift. Radiocarbon dates and stratigraphic relationships suggest that 350 feet of emergence, 500-700 feet of submergence, and emergence of 500-700 feet occurred in a period of only 1,000-2,000 years. The changes in relative sea level during such a short period of time may have resulted from a combination of isostatic uplift of the land, eustatic rise of sea level, superimposed on tectonic movement (Easterbrook, 1963).

The Sumas stade is characterized by the incursion of a valley glacier into the Fraser Lowland during the final stages of emergence from the sea. The associated Sumas drift deposits occur north and east of the proposed Cogeneration Project site.

2.1.3 Generalized Geology and Geologic Units

Quaternary glacial and nonglacial unconsolidated sediments primarily characterize the regional geology surrounding the proposed Cogeneration Project site. Older sedimentary rocks and crystalline rocks are exposed in the Cascade Range to the east, the Coast Range to the north, the Chuckanut Mountains to the southeast, the San Juan Islands to the southwest, and the Gulf Islands and Vancouver Island to the west. These sedimentary and crystalline rocks form a bedrock layer under the Cogeneration Project site. The focus of the discussion will be on the unconsolidated sediments underlying the proposed Cogeneration Project site. Figure 2.1-2 is a generalized surface geologic map of the area surrounding the proposed Cogeneration Project site.

Igneous and metamorphic rocks present in mountains proximal to the Whatcom Basin include the pre-Devonian-age granitic and hornblende-rich rocks of the Turtleback Complex exposed in only a few localities (Lummi Island) and a pre-Jurassic-age phyllite exposed in the Chuckanut Mountains to the southwest (Easterbrook, 1973 and 1976).

Sedimentary rocks include the Paleocene to Late Cretaceous-age Chuckanut Formation and the Eocene-age Huntingdon Formation. The Chuckanut Formation includes a thick sequence of sandstone, conglomerate, shale, and bituminous to sub-bituminous coal. The Chuckanut Formation makes up most of the Cascade foothills to the east and the Chuckanut Mountains to the southwest. The Huntingdon Formation was deposited unconformably on the Chuckanut Formation. The Huntingdon Formation consists of mostly sandstones and shales, similar to the Chuckanut Formation. Unconsolidated Quaternary deposits overlie the Chuckanut and Huntingdon Formations over much of the lowland areas (Easterbrook, 1973 and 1976).

Quaternary unconsolidated deposits were formed as a result of glacial advances and retreats as well as from at least two incursions of seawater during the Everson interstade. Drift deposits of the Vashon stade of the Fraser glaciation include the Vashon till and Esperance sand. These Vashon drift deposits are found at depth below the Everson interstade deposits and also exposed in sea cliffs along the Strait of Georgia shoreline. The Esperance sand is an outwash sand and gravel deposited from meltwater streams during the Vashon stade glacial advance. Esperance sand forms beds as much as 45 feet thick that pinch out laterally. Vashon till was deposited as a lodgement till at the base of the advancing glacier and overlies the Esperance sand. The Vashon till is a compact mixture of pebbles and cobbles in a matrix of clay, silt, and sand. The Vashon till forms a massive layer 10 to 30 feet thick that underlies much of the lowland area (Easterbrook, 1973 and 1976).

Deposits of the Everson interstade underlie much of the area around the proposed Cogeneration Project site. The Everson interstade deposits consist of two fossiliferous glaciomarine deposits separated by a fluvial sand. From bottom to top, these units include the Kulshan glaciomarine drift, the Deming sand, and the Bellingham glaciomarine drift (Armstrong and others, 1965; and Easterbrook, 1973 and 1976).

The Kulshan glaciomarine drift consists of a fossiliferous blue-gray, unsorted, and unstratified mixture of silt, clay, sand, and pebbles. The Kulshan drift is 25 feet or more in thickness. The Kulshan drift was deposited on the sea floor as debris melted out from glacial ice. The Kulshan drift is covered by younger deposits over most of the Fraser Lowland and is exposed at sea cliffs along Bellingham Bay and the Strait of Georgia (Armstrong and others, 1965; and Easterbrook, 1973 and 1976).

The Deming sand consists of brown, stratified, well-sorted, medium to coarse sand with some layers of silt, clay, and gravel. The Deming sand is about 30 feet in thickness and contains a peat bed near its base. The Deming sand was deposited as stream sediments. The Deming sands occur continuously beneath upland areas east of Bellingham Bay extending to Cedarville. The Deming sand is absent below other upland areas indicating nondeposition or post depositional erosion. The Deming sand is covered by younger deposits, typically Bellingham drift, over most of the Fraser Lowland and is exposed at sea cliffs along Bellingham Bay (Armstrong and others, 1965; and Easterbrook, 1973 and 1976).

The Bellingham glaciomarine drift consists of a fossiliferous blue-gray, unsorted, and unstratified pebbly sandy silt and pebbly clay. The Bellingham drift is 70 feet or more in thickness. The Bellingham drift was deposited on the sea floor as debris melted out from glacial ice. The Bellingham drift mantles many of the upland areas and overlies the Deming sand (Armstrong and others, 1965; and Easterbrook, 1973 and 1976).

Deposits of stratified sand and gravel mantle the Bellingham drift in places and were likely the result of wave action reworking the Bellingham drift resulting in the removal of most of the fine sediments. These sand and gravel deposits, where they occur, are 10 feet or less in thickness (Easterbrook, 1973 and 1976).

Sumas drift deposits fill most of the low-lying areas and valleys. These deposits include outwash sand and gravel, terrace deposits, and silt and clay of estuarine origin. These Sumas drift deposits do not occur beneath the area of the proposed Cogeneration Project site but do occur in the low-lying area to the north and in the valley of the Nooksack River to the east (Easterbrook, 1973 and 1976).

Recent alluvial deposits occur in the Nooksack River floodplain to the east. Beach deposits occur along the Strait of Georgia and Bellingham Bay at the base of the sea cliffs and form sand spits created by long shore currents (Sandy Point and Semiahmoo Spit). Peat deposits occur in low-lying areas and depressions in floodplains, Sumas outwash plains, and on the Bellingham drift (Easterbrook, 1973 and 1976).

2.1.4 Structural Geology

Between northern California and southern British Columbia, the convergent plate boundary consists of fragments of the former Farallon plate that have been obliquely converging on, colliding with, and subducting beneath the North American plate. The largest of these oceanic plates is the Juan de Fuca plate. The Juan de Fuca plate is thrust beneath the North American plate along a zone known as the Cascadia subduction zone. The Cascadia subduction zone is located approximately 200 miles west of the proposed Cogeneration Project site. The arched subducted slab of the Juan de Fuca plate lies between 25 and 40 miles beneath the Puget lowland (Galster and Laprade, 1991).

Beds of the Chuckanut and Huntingdon Formations, exposed southeast of the proposed Cogeneration Project site, have been folded into a series of north trending anticlines and synclines. Erosion of these folded rocks over millions of years has eroded the less resistant beds of shale and coal more rapidly then the more resistant sandstone and conglomerate beds (Easterbrook, 1973). A similar structure may exist below the unconsolidated Quaternary deposits.

Depth to bedrock surface beneath the unconsolidated Quaternary deposits varies considerably indicating a preglacial erosional surface of substantial relief. The bedrock surface in the northern part of Whatcom County is much more deeply buried than that in the southern part. Bedrock was encountered in a well west of Ferndale at a depth of 320 feet, and at 615 feet in a well north of Ferndale. Near Blaine, a well penetrated 746 feet of sediments without reaching bedrock (Easterbrook, 1973). The presence of thick sequences of relatively undeformed Quaternary deposits in the lowland areas obscures the underlying structure.

2.2 Site Geology

2.2.1 Site Geology and Stratigraphy

The Whatcom Basin consists of seven upland plateau areas and three lowland terraces. The proposed Cogeneration Project site is situated on the Mountain View Upland, one of the seven upland areas. Two lowland areas that include the Custer Trough to the north and the Nooksack River floodplain to the south bound the Mountain View Upland (Newcomb and others, 1949; and Goldin, 1992).

To date, there have been no geotechnical or subsurface environmental investigations directly on the proposed Cogeneration Project site. Geotechnical and environmental investigations have been conducted at the adjoining BP Cherry Point Refinery to the west. Several cross sections have been developed for the area surrounding the proposed Cogeneration Project site and including the area of BP Cherry Point Refinery. Figure 2.2-1 depicts the locations of area wells and the cross-sections. These cross-sections are included as Figures 2.2-2, 2.2-3, 2.2-4, and 2.2-5. Figures 2.2-2, 2.2-3, and 2.2-4 were developed from local water well logs and monitoring well logs from the BP Cherry Point Refinery investigations. Figure 2.2-5 cross-section was adapted from CH2MHill, 1985. Attachment A includes water well logs and Attachment B includes monitoring well logs from the BP Cherry Point Refinery investigations.

Based on the cross-sections and other available information, the following stratigraphy has been developed for the for the proposed Cogeneration Project site:

Quaternary

Sand and Gravel overlying the Bellingham Drift (Qbg): A thin mantle consisting primarily of sand, from well sorted sand to silty sand. This unit is interpreted to be wave reworked material from the Bellingham drift (Easterbrook, 1976). This unit ranges up to 10 feet in thickness and may or may not be present at the proposed Cogeneration Project site.

Bellingham Drift (Qb): The Bellingham glaciomarine drift consists of a fossiliferous blue-gray, unsorted, and unstratified pebbly sandy silt and pebbly clay. The Bellingham drift may be 70 to 80 feet in thickness below the proposed Cogeneration Project site. The Bellingham drift includes an upper weathered zone as much as 23 feet in thickness.

Deming Sand (Qd): The Deming sand consists of brown, stratified, well-sorted, medium to coarse sand with some layers of silt, clay, and gravel. The Deming sand may be 30 to 40 feet in thickness below the proposed Cogeneration Project site. The Deming sand appears to be discontinuous or pinches out to the east and northeast (Figures 2.2-3 and 2.2-4).

Kulshan Drift (Qk): The Kulshan glaciomarine drift consists of a fossiliferous blue-gray, unsorted, and unstratified mixture of silt, clay, sand, and pebbles. The Kulshan drift may be as much as 100 to 120 feet in thickness at the proposed Cogeneration Project site. In some cases, this unit was not distinguishable in the well logs. In these cases, the Kulshan drift was lumped into the undifferentiated sedimentary deposits (Qu).

Undifferentiated sedimentary deposits (Qu): These are unconsolidated sedimentary deposits that were not separated or were not distinguishable on the well logs. The unconsolidated sedimentary deposits may include the Kulshan drift, Vashon till, Esperance sand, and other glacial and nonglacial sediments below the Bellingham drift.

Pre-Quaternary

Undifferentiated sedimentary rock (TMu): These are Tertiary-Mesozoic sedimentary rocks (bedrock) that were encountered in wells to the north and northeast of the proposed Cogeneration Project site (Figures 2.2-2 and 2.2-3). These rocks were encountered at 210 and 256 feet below ground surface to the north and northeast. One well to the west (Figure 2.2-3) at 650 feet below ground surface did not encounter bedrock. These sedimentary rocks are likely Chuckanut or Huntingdon Formation with similar structure as in their exposures to the southeast.

2.2.2 Engineering Properties

Subsurface explorations and laboratory testing of retrieved samples were conducted near the proposed Cogeneration Project site in early 1999 (Shannon & Wilson, 1999). The field exploration included the advancement of several soil borings near the proposed Cogeneration Project site (Figure 2.2-1). The purpose of the explorations and laboratory testing was to identify and characterize subsurface conditions for the design and construction of an electric substation and transmission line. Conditions beneath the proposed Cogeneration Project site are expected to be similar based on the proximity of the exploratory borings to the proposed Cogeneration Project site. The Shannon & Wilson (1999) boring logs are included as Attachment C. A site-specific exploration program will be developed to characterize subsurface conditions beneath the proposed Cogeneration Project site where additional information may be needed.

According to Shannon & Wilson (1999), the exploratory borings in the Billingham Drift encountered a medium stiff to very stiff (desiccated), slightly gravelly, slightly sandy to sandy clay to depths ranging from 10 to 21 feet. Below this desiccated zone, the Billingham Drift changes to a very soft to medium stiff, slightly gravelly, slightly sandy, silty clay. The remaining lower sections of the Bellingham Drift changed to a hard, slightly gravelly, silty clay, which was believed to be glacially overconsolidated. Depth to the overconsolidated soils ranged from 33 to 84 feet. Depth to which groundwater was observed ranged from 12 feet to greater than 49.5 feet.

Atterberg limits and natural water content were determined on selected samples. The ranges are summarized below:

Liquid Limit (%)	26 – 55
Plastic Limit (%)	14 – 19
Plasticity Index (%)	12 – 36
Water Content (%)	19.5 – 34.9

No specific foundation plans have yet been developed for the proposed Cogeneration Project. However, future foundation design and construction will be based on existing and additional geotechnical studies, as required.

3. SOILS

3.1 Soil Types

The general soil map unit that encompasses most of the proposed Cogeneration Project site and vicinity is the Birchbay-Whitehorn unit (Goldin, 1992). Elements of the Whatcom-Labounty unit and the Kickerville-Barneston-Everett unit are also present in the vicinity.

- Birchbay-Whitehorn unit soils are very deep, moderately well drained and poorly drained, level to gently sloping soils developed on glaciomarine drift plains.
- Whatcom-Labounty unit soils are very deep, moderately well drained and poorly drained, level to very steep developed dominantly on glaciomarine drift plains.
- Kickerville-Barneston-Everett unit soils are very deep and deep, well drained and somewhat excessively drained, level to very steep developed on outwash terraces and moraines.

The following soil types exist at or near the proposed Cogeneration Project as shown on Figure 3.1-1:

12 - Birch Bay silt loam (0 to 3 percent slopes) - This soil type encompasses the northern portion of the proposed Cogeneration Project site. This very deep, moderately well drained soil is on wave-reworked glaciomarine drift plains. It formed in an admixture of volcanic ash and loess over glaciofluvial deposits and glaciomarine drift. Permeability is moderate in the upper part, very rapid in the sandy upper part of the substratum, and slow in the loamy lower part. Available water capacity is high. Runoff is very slow and there is no hazard of erosion.

80 – Kickerville silt loam (0 to 3 percent slopes) - This soil type is found on a low hill north of the proposed Cogeneration Project site north of Grandview Road. This very deep, well-drained soil is on outwash terraces. It formed in a mixture of loess and volcanic ash over glacial outwash. Permeability is moderate in the upper part and very rapid in the substratum. Available water capacity is high. Runoff is very slow and there is no hazard of erosion.

93 – Labounty silt loam (0 to 2 percent slopes) - This soil type encompasses the eastern portion of the proposed Cogeneration Project site. This very deep, poorly drained soil is on wave-reworked glaciomarine drift plains. It formed in volcanic ash, loess, glaciofluvial deposits, and glaciomarine drift. Permeability is slow and available water capacity is high. Runoff is very slow, but the soil may be ponded during the winter and spring. There is no hazard of erosion.

184 – Whitehorn silt loam (0 to 2 percent slopes) – This soil type encompasses most of the proposed Cogeneration Project site. This very deep, poorly drained soil is in depressions on glaciomarine drift plains. It formed in glaciomarine drift with an admixture of loess and volcanic ash. Permeability is moderately slow and available water capacity is high. Runoff is very slow and there is no hazard of erosion.

3.2 Erosion Susceptibility and Mitigation

All soil at and in the vicinity of the proposed Cogeneration Project site is described as presenting no hazard of erosion (Goldin, 1992). Quantitatively the erosion susceptibility of a given soil type to sheet and rill erosion can be described using the erosion factor K. Factor K is one of six factors used in the Universal Soil Loss Equation (USLE) to predict the average annual rate of soil loss by sheet and rill erosion in tons per acre per year. The estimates are based primarily on percentage of silt, sand, and organic matter (up to 4 percent) and on soil structure and permeability. Values of K range from 0.05 to 0.69. The higher the value, the more susceptible the soil is to sheet and rill erosion by water.

The following is a list of erosion factors for the soils located at and in the vicinity of the proposed Cogeneration Project site (Grodin, 1992):

Soil Type	Depth (in.)	K Factor
Birch Bay (12)	0-8	0.32
	8-24	0.24
	24-42	0.10
	42-60	0.28
Kickerville (80)	0-9	0.28
	9-22	0.32
	22-32	0.15
	32-60	0.02
Labounty (93)	0-12	0.32
	12-29	0.32
	29-37	0.37
Whitehorn (184)	0-10	0.37
	10-18	0.49
	18-26	0.24
	26-60	0.49

Mitigation measures to minimize erosion during construction and operation and proposed procedures to control erosion and sedimentation during construction are described in Appendix F: Technical Report on Water. Best Management Practices (BMPs) will be implemented during construction for erosion control and prevention. Site soils are fairly impermeable and further reduction of soil permeability in construction areas will be negligible. All soil at and in the vicinity of the proposed

Cogeneration Project site is described as presenting no hazard of erosion (Goldin, 1992). Disposition of excess excavation materials is discussed in section 3.3 below. .

3.3 Foundation Preparation

Construction activities including foundation preparation, grading, and filling are described in Appendix D: Technical Report on Project Description. There are no streams that will be directly affected by these activities. Surface water runoff is discussed in Appendix F Technical Report on Water. Because the existing slopes range from 0.5% to 1%, extensive grading of the site will not be required. It is anticipated that some unsuitable materials may require removal and that some imported fill of suitable quality will be needed for replacement, site preparation, and backfill. General construction methods for foundation preparation will involve site survey and staking, site preparation for runoff control, hand, and machine excavation, fill and compaction of structural base, installation of structural support piles, and construction of reinforced concrete footings and foundations.

Construction activities including trench backfill and other fill activities are described in Appendix D: Technical Report on Project Description. Sources of imported fill materials are described in section 3.4 of this report. Project specifications and construction plans will be developed at a later date to address specific fill material requirements, gradation, drainage, compaction, and wet weather work. Only minimal excess excavated material will be generated during construction. Excavated material will be used as backfill where possible. Excess material will be removed to approved and permitted landfills or used as fill at other off-site construction sites as available. Piles of excavated materials will be stabilized and protected using BMPs in accordance with a Stormwater Pollution Prevention Plan (SWPPP) and Temporary Erosion and Sedimentation Control Plan (TESC) as described in Appendix F: Technical Report on Water. Wetland areas will be affected as a result of the proposed Cogeneration Project as described in Appendix H: Technical Report on Plants and Animals. The placement of impermeable fill in wetland areas will occur in selected areas as a result of the construction of the proposed Cogeneration Project. However, these wetland areas occur in low-lying areas over existing relatively impermeable native soils. Unsuitable moisture sensitive soil will be removed and replaced with suitable materials where necessary for site and foundation preparation.

3.4 Borrow Sources for Fill and Construction Bulk Materials

Construction bulk materials including soil, sand and gravel would be supplied locally from existing permitted sources and quarries. The total quantity of imported fill material is estimated to be approximately 126,000 cubic yards. This quantity includes pavement base course material for the plant roadway and parking area and gravel surfacing material for the switchyard and power block areas. Impacts to the local construction bulk material sources and quarries will be consistent with those types of extractive land uses within the limitations of the permit requirements for these facilities.

3.5 Topographic Changes at Borrow Sources

The total quantity of imported fill material is estimated to be approximately 126,000 cubic yards. Topographic changes to local construction bulk material sources and quarries will be consistent with those types of extractive land uses within the limitations of the permit requirements for these facilities.

3.6 Potential for Contaminated Soil

There is a very low potential for encountering contaminated soil within the proposed Cogeneration Project site and electrical transmission route. Based on a review of aerial photographs and interviews with long-time BP employees, these areas were used for agriculture before the refinery was built. Aerial photographs were reviewed for the years 1951, 1961, 1975, 1985, and 1995.

Soils will be sampled and inspected before and during site clearing, grading, trenching and other excavation activities. Despite these precautions, if suspect contaminated soil is encountered during trenching and other excavation activities, these activities will be stopped. Qualified personnel will respond to assess hazards and perform characterization. Treatment and/or disposal of would depend on the type of contamination found.

4. NATURAL HAZARDS

4.1 General Description of Natural Hazards

Natural hazards discussed within Appendix G: Technical Report on Earth or in other sections of the Technical Appendices include the following:

- Flooding,
- Seismic hazards,
- Volcanic hazards, and
- Tsunami hazards.

Design measures that would be implemented to protect the proposed Cogeneration Project from these natural hazards. The Cogeneration Project will be designed and constructed in strict conformance to applicable Federal, State, local and industry building codes and standards for thermal power plants as identified in Attachment A of Appendix A – Project Description Technical Report. These Codes and Standards account for climatic conditions and natural hazards that exist for the specific site. All final design and construction specifications will be reviewed and approved by EFSEC prior to construction. Construction quality control and documentation will be made available for regulatory inspection and approval.

4.2 Flooding Hazards

A thorough discussion of flood hazards and erosion control is provided in Appendix F: Technical Report on Water. The proposed Cogeneration Project and all associated components are located outside of 5-, 100-, or 500-year floodplains. Site soils are fairly impervious (clay/silt), topography is relatively flat, and the vegetation is well established. Based on these factors, there is a very low risk for flooding and soil erosion hazards. BMPs will be implemented during construction for erosion control and prevention (see Appendix D Project Description Technical Report for more details). Therefore, the potential for flooding hazards to occur to the Cogeneration Project is very low.

4.3 Seismic Hazards

4.3.1 Tectonic Setting and Historical Seismicity of Northwestern Washington

This section describes the general tectonic setting and historical seismicity of the Pacific Northwest. The major historical earthquakes and their known effects in Whatcom County are briefly described. The evidence for known geological structures capable of generating moderate to large earthquakes that could produce significant earthquake shaking at the Proposed Cogeneration Project site is outlined.

Estimates of earthquake ground accelerations based on an existing probabilistic seismic hazard model for the United States are provided. The possible earthquake-related hazards at the site are described. Proposed geotechnical investigations to address identified earthquake hazards are also outlined.

4.3.1.1 Present Day Regional Tectonic Setting

Northwestern Washington State is located along the western margin of the North American tectonic plate, near the boundary of the Juan de Fuca plate (Figure 4.3-1). The Juan de Fuca plate is at present moving northeastward at an average rate of about 40 mm/year relative to the North American plate. The Juan de Fuca plate is still forming at its boundary with the Pacific plate farther west under the Pacific Ocean.

These relative plate motions result in the Juan de Fuca plate subsiding below the North American plate along the Cascadia Subduction zone, which lies offshore of coast northern California, Oregon, Washington, and British Columbia (Figure 4.3-2). Plate interactions at the subduction zone result in the creation of faults and folds, and are thought to generate most of the earthquakes in the Pacific Northwest.

Major earthquakes in the Pacific Northwest have four principal origins (Figures 4.3-1 and 4.3-2):

- Shallow earthquakes from active spreading at the boundary of the Pacific and Juan de Fuca plates;
- Large interplate thrust earthquakes at the boundary of the North American and Juan de Fuca plates;
- Deeper earthquakes resulting from internal stresses associated with the bending and arching of the Juan de Fuca plate as it is subducted beneath the North American plate; and
- Shallow crustal seismicity in the overlying North American plate, particularly where it overlies the change in subduction direction of the Juan de Fuca plate.

In northwestern Washington State, the Juan de Fuca plate makes a marked change in subduction direction — from an easterly direction south of Puget Sound, to a northeast direction beneath Vancouver Island. This change in direction has formed an uplifted arch structure in the Juan de Fuca plate beneath Puget Sound (McCrumb et al., 1989). This arch may be the cause of the Olympic Mountains, the increased seismicity in the overlying North American plate and the large, deep historical earthquakes in southern Puget Sound.

4.3.1.2 Historical Seismicity

Western Whatcom County is located in a region of moderate historical seismicity and is within the Unified Building Code Seismic zone 3 (Figure 4.3-3). Earthquake records from the National Earthquake Intensity Database (National Geophysical Data Center) show intensities of Modified Mercalli (MM I) III or greater have been recorded 34 times in Bellingham and 12 times in Ferndale (6 miles southeast of Proposed Cogeneration Project site) from the late 19^{th} Century to 1985. These felt effects come from earthquakes located both within and distant from Whatcom County.

The largest earthquake known from the Pacific Northwest occurred on 26 January 1700. This earthquake probably occurred along the boundary between the Juan de Fuca and North American plates. While the magnitude of the event is not well know, it was probably larger than Magnitude (M, approximately equivalent to the Richter scale) 8, and may be as large as M 9. It generated a major tsunami that affected the west coast of North America and was recorded in Japan (Satake et al., 1996). Geological evidence summarized by Atwater et al. (1995) indicates that these large interplate earthquakes may occur about every 1000 years.

Historical and instrumental records reveal that at least 24 earthquakes of magnitude 4.0 or greater have occurred within 160 km (100 miles) of the Proposed Cogeneration Project site since the early 1970s are shown on Figure 4.3-4 and listed in Table 4.3-1. Twelve (12) of these earthquakes were located within 50 km of the Proposed Cogeneration Project site.

Most of the larger instrumentally recorded earthquakes ($M \geq 6.5$) in Washington State have been located in the southern part of the Puget Lowland, near Seattle and Olympia in 1949, 1965, and 2001. These earthquakes have occurred within the upper part of the Juan de Fuca plate at depths greater than 25 km.

The most significant local earthquake was the M 5.2 Deming earthquake of 14 April 1990. It had an epicenter about 40 km south west of the Proposed Cogeneration Project site (Dragovich et al., 1997). The main shock and aftershocks occurred at very shallow depths (3-4 km). Although no surface fault rupture was recorded, Dragovich et al. (1997) believe that the earthquake was caused by subsurface movement along a shallow, northeast-dipping thrust fault. They inferred from a range of local topographic features that this fault has moved repeatedly over the last ca. 15,000 years. While these interpretations are speculative, this earthquake demonstrates that moderate magnitude earthquakes can occur at very shallow depths close to the Proposed Cogeneration Project site.

TABLE 4.3-1

Significant Historical Earthquakes in Northwestern Washington and Southern British Columbia within 100 Miles of the Cogeneration Site (1)

Date(3) (dd/mm/y)	Latitude (°North)	Longitude (°West)	Magnitude(2) (M)	Depth(4) (km)	Maximum Intensity (MMI)(6)	Approx. Distance to Cherry Point(5) (miles)
14/12/1872	48.8	121.4	7.4	?	IX	127
17/03/1904	48.5	122.8	5.3	?	V	24
11/01/1909	49.0	122.7	6.0	?	VII	11
18/08/1915	48.5	121.4	5.6	?	V	62
24/01/1920	48.8	123	5.5	?	VI	15
31/12/1931	47.5	123.0	4.8	?	VI	93
18/07/1932	47.75	121.83	5.2	?	VI	84
13/11/1939	47.5	122.5	5.75	?	VII	92
29/11/1943	48.4	122.9	4.8	?	VI	31
15/02/1946	47.4	122.67	5.75	18	VII	99
15/05/1954	48.0	122.00	5.0	?	VI	65
26/01/1957	48.33	122.43	5.0	?	VI	36
10/09/1960	47.70	122.70	4.6	25	VI	78
24/01/1963	47.60	122.10	4.5	17	VI	89
14/07/1964	49.00	122.60	4.6	13	VI	12
10/11/1969	48.50	121.40	4.7	?	V	62
16/04/1975	47.57	122.90	4.0	47	V	88
16/05/1976	48.80	123.36	5.4	62	VI	31
02/09/1976	48.21	122.76	4.3	24	VI	43
10/07/1977	48.53	122.45	4.3	11	VI	23
05/03/1977	48.06	123.00	4.0	57	IV	55
11/03/1978	47.42	122.71	4.8	25	VI	98
31/03/1978	47.42	122.71	4.2	23	VI	98
19/08/1978	48.63	123.55	4.3	32	V	42
23/08/1978	48.38	123.2	4.4	17	V	39
31/12/1978	47.58	121.85	4.0	20	VI	94
09/11/1979	49.00	124.42	4.3	28	IV	80
29/11/1979	48.59	122.40	4.1	21	V	21
28/08/1983	47.93	122.85	4.2	51	IV	62
14/02/1989	48.43	122.23	4.2	0	VI	34
05/03/1989	47.81	123.26	4.6	46	V	77
06/03/1989	48.43	122.23	4.2	1	V	34
18/06/1989	47.41	122.78	4.4	44	V	98
02/04/1990	48.83	122.19	4.3	0	VI	22
03/04/1990	48.84	122.18	4.8	1	V	22
14/04/1990	48.85	122.16	5.2	12	VI	23
19/02/1991	49.70	122.72	4.3	5	V	60
22/02/1996	49.90	123.90	4.1	2	IV	92
23/06/1997	47.60	122.57	5.0	7	VI	85
24/06/1997	49.24	123.62	4.6	3	IV	51

Notes:

(1) Locations, depths, and magnitudes were obtained from the USGS. October 2001.Earthquake Catalog for 1973-Oct 2001 and USGS. October 2001. Significant Worldwide Earthquake Catalog (2150 B.C.-1994 A.D.) .

(2) Earthquake magnitudes are M_b, M_s , M_w and M_L.

(3) Time is Universal time.

(4) Earthquake depths before 1969 are approximate only.

(5) Distance to Proposed Cogeneration Project site based on its location at 48.833°N, 122.673°W

(6) Modified Mercalli Intensity scale after Bolt (1993).

4.3.1.3 <u>Recent Faulting and Tectonic Uplift</u>

No surface fault rupture is known to accompany large historical earthquakes in Washington State, probably because nearly all of the larger historical earthquakes have had relatively deep hypocenters. Evidence of land deformation associated with prehistoric earthquakes (cosesimic) has been described from several places in western Washington. Geological evidence of coseismic deformation during the last 15,000 years includes:

- Macaulay Creek Thrust in western Whatcom County (Dragovich et al., 1997)
- The Devils Mountain fault zone in the eastern Strait of Juan de Fuca (Johnson et al., 2000);
- The southern Whidbey Island fault in Puget Sound (Johnson et al., 1996)
- The Seattle Fault in central Puget Sound (Bucknam, 1992)
- Repeated subsidence of coastal lowlands during the last 7000 years in northern California, Oregon, Washington and southern British Columbia (Atwater et al., 1995)

Recent analysis by Easterbrook et al. (unpublished) infers the existence and recent activity of two northeast-southwest-trending faults to the east of the Proposed Cogeneration Project site. Easterbrook et al. (unpublished) infer that a 10 km-wide structural valley (graben) formed from repeated movement along the Sumas and Vedder Mountain faults. Easterbrook et al. do not know the western extent of these faults. Their map shows that the Vedder Mountain fault could extend into Lummi Bay. The location and coseismic activity of these faults is controversial. However, neither fault trends into the Proposed Cogeneration Project site.

4.3.2 Earthquake Ground Shaking

Earthquake shaking expected at the Proposed Cogeneration Project site and other environmental hazards commonly associated with earthquake occurrence and strong ground shaking is described in this section.

Ground shaking is the most pervasive earthquake hazard. The amplitude, frequency and duration of the shaking at a site are related to the following three major factors:

- Magnitude of the earthquake;
- Distance of the site from the earthquake source; and
- Earth materials underlying the site.

In general, the closer a site is to the source of the earthquake, the greater the earthquake shaking.

4.3.2.1 Estimates of Peak Horizontal Ground Shaking (PGA) at the Site

A useful way to describe earthquake shaking for engineering purposes is in terms of peak horizontal ground acceleration (PGA). This measure provides useful information about the forces that might be applied to engineered structures during earthquake shaking.

The US Geological Survey (USGS) National Seismic Hazard Mapping Project has completed a probabilistic seismic hazard assessment for the conterminous United States. They estimate probabilistic seismic hazard by considering the probability of occurrence of all earthquakes, the probability of all the ground motions associated with these earthquakes, and calculating the probability that a certain level of shaking will be exceeded in a chosen time period. The 10 % probability of exceeding a mean PGA value in a 50-year period is a common measure used in engineering studies[1]. This is equivalent to the mean ground motion with a return period of 475 years.

Table 4.3-2 shows the PGA values calculated by USGS for the Proposed Cogeneration Project site for return periods from 475 years to 4975 years. These values indicate that the Proposed Cogeneration Project site can be expected to receive a moderate level of earthquake ground shaking in a 475-year period. These ground motions are calculated for sites underlain by rock. Ground motions on deep soil sites, such as Cherry Point, can be expected to be different (see Section 4.3.2.2 below for more information).

TABLE 4.3-2

Existing Estimates of Mean PGA for Rock Sites at
the Proposed Cogeneration Project Site (USGS, Nov. 2001)

Probability of Exceedance	Return Period (years)	USGS	Canadian Building Code	Accepted Value
10% in 50 yrs	475	0.23g	0.16-0.23g	0.23g
5% in 50 yrs	975	0.31g		0.31g
2% in 50 yrs	2475	0.44g		0.44g
1% in 50 yrs	4975	0.54g		0.54g

The USGS also provide a deaggregation of the calculated hazard. This deaggregation splits the total hazard into its contributing earthquake sources for distance and magnitude classes. Deaggregation of the Cherry Point hazard shows that the 475-year PGA value has approximately equal contributions from moderate local magnitude earthquakes and larger, but more distant deeper earthquakes. The hazard from large magnitude earthquakes at the subduction zone has been incorporated into the hazard estimate.

[1] This probability can be equally expressed as a 90% probability that the ground motion will **not** be exceeded in 50 years.

All of western Washington, including the Proposed Cogeneration Project site, lies in Seismic Zone 3 of the 1997 Uniform Building Code (UBC). The region of Canada immediately north of Cherry Point lies within Canadian Building Code seismic acceleration Zone 2. This Canadian zonation specifies an acceleration with a 10% probability of exceedance in 50 years of 0.16-0.23g. This acceleration is comparable to accelerations estimated from US hazard models (Table 4.3-2).

4.3.2.2 Assessment of Earthquake Ground Shaking Effects

Potential effects of ground motions at the Proposed Cogeneration Project site and surrounding area include:

- Amplification of ground motions by subsurface materials (site effects);
- Earthquake-triggered slope instability;
- Soil liquefaction and lateral spreading; and
- Surface fault rupture.

Site Amplification of Earthquake Ground Shaking:

Existing investigations for sites close to the Proposed Cogeneration Project site suggest that the site is underlain by more than 60 m of Quaternary-age glacial and glaciomarine deposits. The upper 30 m of these deposits are typically soft to medium stiff clay to about 15 m (50 feet) below ground surface. Below about 15 m they are very stiff to hard clay.

The upper 15 m of sediment may have low average shear wave velocity. Low average shear wave velocity in the upper 30 m of soil is important for earthquake site response. Low average shear wave velocity deposits can filter out high-frequency ground motions and amplify the longer period motions. Amplification of longer period motions is potentially more damaging to engineered structures. The magnitude of site amplification will depend primarily on the frequency content and intensity of the ground motions and local soil conditions. Shear wave velocity is used to characterize the soil profile type in the 1997 Uniform Building Code.

Topographic amplification of earthquake shaking is not expected because of the low relief of the site.

Dynamic Slope Instability:

The site does not contain significant slopes. Earthquake-triggered slope instability is not a hazard at the Proposed Cogeneration Project site.

Soil Liquefaction:

Soil liquefaction is a sudden reduction in the strength and stiffness of a soil by earthquake shaking or other rapid loading. Liquefaction and related phenomena have been responsible for tremendous amounts of damage in historical earthquakes around the world.

Liquefaction occurs in saturated soils. These are soils in which the space between individual particles is completely filled with water. Earthquake shaking can cause the water pressure to increase to the point where the soil particles can easily move with respect to each other. When liquefaction occurs, the strength of the soil decreases and, the ability of the soil to support foundations for buildings and bridges is reduced. Liquefaction typically occurs in saturated sandy soils.

Preliminary analysis of subsurface materials close to the Proposed Cogeneration Project Site indicates a lack of sand layers within the soft - stiff clay deposits. Without significant sand layers the potential for liquefaction at the site is low.

Surface Fault Displacement:

No active faults are known beneath the site. Preliminary analysis of aerial photography and geologic maps indicates that the hazard from surface faulting at the site is extremely low.

4.3.3 Seismic Design Studies

If soft soils with low average shear wave velocity are confirmed beneath the site during site specific geotechnical studies, then site-specific dynamic response analysis should be completed. This analysis is needed to assess the potential amplification of earthquake ground motions through these soft soils. The site–specific dynamic response analysis will be used for design considerations to mitigate potential seismic impacts.

4.4 Volcanic Hazards

Potential geologic hazards due to volcanism can be divided into primary and secondary volcanic processes. Primary volcanic processes include: lava flow, earthquakes associated with volcanism, ground deformation (uplift, subsidence, faulting), tephra (ash) fall, pyroclastic flow and surge, and explosion phenomena (air shock overpressure). In addition to these primary processes, secondary effects associated with volcanic eruptions include: flooding, mudflows, drainage changes caused by lava flow dams, and wildland fires caused by lava flows and other incandescent volcanic debris.

The majority of these volcanic processes and effects are limited to the near vicinity of a volcano (within about 20 miles) and are influenced by the nearby topography (Lipman and Mullineaux, 1981). Exceptions to these limits are the effects of volcanic earthquakes and tephra fall, which may impact areas many miles from a volcano.

There are five major composite volcanoes (or stratovolcanoes) in the State of Washington that are all part of the Cascade Range, a volcanic arc that stretches from southwestern British Columbia to northern California. These five volcanoes are Mount Baker, Glacier

Peak, Mount Rainier, Mount St. Helens, and Mount Adams. With the exception of Mount Adams, each of the Washington volcanoes have erupted within the last 250 years (Pringle, 1994). Several composite volcanoes are present in the State of Oregon, including Mount Hood.

Of the five Washington volcanoes, only Mount Baker and, to a far lesser degree Glacier Peak, have any potential to affect the proposed Cogeneration Project site. Mount Baker is located approximately 45 miles east and Glacier Peak is located approximately 100 miles southeast of the proposed Cogeneration Project site. Only Mount Baker and Glacier Peak are discussed specifically in this report. Based on the relative distances of the other Cascade volcanoes, only tephra fall would be a potential concern.

4.4.1 Mount Baker

Potential volcanic hazards from Mount Baker are depicted on Figures 4.4-1, 4.4-2, and 4.4-3 (adapted from Gardner and others, 1995). The main hazards at Mount Baker are from debris flow and debris avalanches. Based on Figures 4.4-1, 4.4-2, and 4.4-3, the proposed Cogeneration Project site is not vulnerable to any volcanic hazards except for tephra. The nearest volcanic hazard to the proposed Cogeneration Project site, as shown in Figure 4.4-1, would be a debris flow that would inundate the Nooksack River floodplain, approximately 10 miles southeast of the proposed Cogeneration Project site. The largest debris flow in the past 14,000 years on Mount Baker occurred 6,800 years ago. This flow moved down the Middle Fork of the Nooksack to the main Nooksack and can be traced as far downstream as Deming, where it is buried by younger river deposits. It is likely that this debris flow traveled all the way to the mouth of the Nooksack (Gardner and others, 1995).

The annual probability for the deposition of 1 centimeter or more of tephra at the proposed Cogeneration Project site from any Cascade volcano is 0.02% (refer to Figure 4.4-2). The annual probability for the deposition of 10 centimeters or more of tephra at the proposed Cogeneration Project site from any Cascade volcano is less than 0.01% (refer to Figure 4.4-2). Mount Baker has not produced large amounts of tephra and probably will not in the future (Gardner and others, 1995).

No lateral blast deposits have been recognized at Mount Baker. The probability for a future large event is considered low (Gardner and others, 1995). The blast hazard zone is depicted on Figure 4.4-3. The proposed Cogeneration Project site is well outside the limits of the blast hazard zone.

4.4.2 Glacier Peak

Volcanic hazards from Glacier Peak include tephra fall, pyroclastic flows, pyroclastic surges, ballistic ejection, debris avalanches, debris flows (lahars), and floods. Debris flows represent the greatest hazard, followed by tephra fall. The proposed Cogeneration Project site is well outside the limits of the other hazards from Glacier Peak. Debris flows have descended the Suiattle, White Chuck, Sauk, and Skagit River valleys during several eruptive periods (Waitt and others, 1995). These river valleys are relatively distant from the proposed Cogeneration Project site and well to the south and southeast. There are no indications that debris flows from Glacier Peak has affected the Nooksack River valley. The probability of a significant tephra fall occurring at the proposed Cogeneration Project site from Glacier Peak and other Cascade volcanoes is low (Figure 4.4-2).

4.5 Tsunami Hazards

The vulnerability of the proposed Cogeneration Project site to tsunamis that have been historically recorded or interpreted from the geologic record is very low. The proposed Cogeneration Project site is situated at an elevation of 120 feet MSL and more than two miles from the Strait of Georgia. Sea cliffs ranging from 60 to 100 feet high protect most of the shoreline along Strait of Georgia closest to the proposed Cogeneration Project site. Any tsunami that would reach the proposed Cogeneration Project site would leave widespread devastation in its wake. The likelihood of such an occurrence is very low.

The shoreline near the proposed Cogeneration Project site is generally protected from tsunamis generated from distant trans-Pacific sources or Cascadia subduction zone seismic events by the relatively narrow confines of the Strait of Juan de Fuca, Strait of Georgia, and the buffering of the San Juan and Gulf Islands. Similar protection is afforded from tsunamis generated from a large seismic event along the Seattle fault to the south. More commonly, a tsunami could be generated from a local earthquake disturbing the sea floor or by slumping along the front of the Nooksack delta (Easterbrook, 1973). Such a tsunami could have severe local shoreline impacts but is not expected to affect the proposed Cogeneration Project site.

There is evidence for a tsunami in Puget Sound between 1,000 and 1,100 years ago that probably originated from an earthquake on the Seattle fault (Atwater and Moore, 1992). The evidence is the deposition of sand sheets at two locations, Cultus Bay on Whidbey Island and West Point near Seattle. The sand sheet deposition appeared to be localized to shallow tidal marsh areas indicating that the tsuami run up did not affect inland areas beyond the near shore environment.

5. UNIQUE PHYSICAL FEATURES

No unique physical features are present in the vicinity of the proposed Cogeneration Project site including the natural gas pipeline connections and transmission line. The site and surrounding areas are typical of areas found throughout western Whatcom County.

No unique physical features are known to be present at local construction bulk material sources and quarries. Only approved and permitted sources will be used for supplying fill materials for the proposed Cogeneration Project.

6. REFERENCES

Armstrong, J.E., Crandell, D.R., Easterbrook, D.J., Noble, J.B. 1965. Late Pleistocene Stratigraphy and Chronology in Southwestern British Columbia and Northwestern Washington. Geological Society of America Bulletin. Volume 76, No. 3. pp. 321-330.

Atwater, B.F., and Moore, A.L., A Tsunami About 1,000 Years Ago in Puget Sound, Washington. Science. Volume 258. pp. 1614-1617.

Atwater, B.; Nelson, A.; Clague, J.; Carver, G.; Yamaguchi, D.; Bobrowski, P.; Bourgeois, J.; Darienzo, M.; Grant, W.; Hemphill-Haley, E.; Kelsey, H.; Jacoby, G.; Nishenko, S.; Palmer, S.; Peterson, C.; Reinhart, M. 1995: Summary of coastal geologic evidence for past great earthquakes at the Cascadia Subduction zone. Earthquake Spectra 11. 1-18.

Bolt, B.A., 1993. Earthquakes: W.H. Freeman, New York, New York, 331 p.

Bucknam, R.; Hemphill-Haley, E.; Leopold, E. 1992: Abrupt uplift within the past 1700 years at southern Puget Sound, Washington. Science 258. 1611-1614.

Coombs, H.; Milne, W.; Nuttli, O.; Slemmons, D. 1976: "Report of the Review Panel on the December 14, 1872 Earthquake. Web Site: http://spike.geophys.washington.edu/SEIS/PNSN/HIST_CAT/1872/Coombs/

Dragert, H.; Hyndman, R.; Rogers, G.; Wang, K. 1994: Current deformation and the width of the seismogenic zone of the northern Cascadia subduction thrust. Journal of Geophysical Research 99 (B1). 653-668.

Dragovich, J.; Zollweg, J.; Qamar, A.; Norman, D. 1997: The Macaulay Creek Thrust, the 1990 5.2-magnitude Deming Earthquake, and Quaternary geologic anomalies in the Deming area, western Whatcom County, Washington — cause and effects? Washington Geology 25. 15-27.

Easterbrook, D.J. 1976. Geologic Map of Western Whatcom County, Washington. Map I-854-B. United States Geological Survey.

Easterbrook, D.J. 1994. Chronology of the pre-late Wisconsin Pleistocene sediments in the Puget Lowland, Washington. Regional Geology of Washington State. Washington Division of Geology and Earth Resources – Bulletin 80. pp. 191-206.

Easterbrook, D.J., Crandell, D.R., Leopold, E.B. 1967. Pre-Olympia Pleistocene Stratigraphy and Chronology in the Central Puget Lowland, Washington. Geological Society of America Bulletin. Volume 78, No. 1. pp. 13-20

Easterbrook, D.J. 1963. Late Pleistocene glacial events and relative sea level changes in the northern Puget Lowland, Washington. Geological Society of America bulletin. Volume 74, No. 12. pp. 1465-1484.

Easterbrook, D.J. 1973. Environmental Geology of Western Whatcom County, Washington. Western Washington State College Press.

Easterbrook, D.J.,D.C. Engebretson, and D.J. Kovanen. 2001. Potential Seismic Hazards of the Sumas and Vedder Mountain Faults. http://se2-gasp.org/seismic/

Fenneman, N.M. 1917. Physiographic divisions of the United States. Association of American Geographers Annals. Volume 6, pp. 17-98.

Galster, R.W., and Laprade, W.T. 1991. Geology of Seattle, Washington, USA. Bulletin of the Association of Engineering Geologists. Volume 28, No. 3. pp. 239-302.

Goldin, A. 1992. Soil Survey of Whatcom County Area, Washington. Soil conservation Services, United States Department of Agriculture.

Gardner, C.A., Scott, K.M., Miller, C.D., Myers, B., Hildreth, W., and Pringle, P.T. 1995. Potential volcanic Hazards from Future Activity of Mount Baker, Washington. United States Geological Survey Open-File Report 95-498.

Johnson, S.; Potter, C.; Armentrout, J.; Miller, J.; Finn, C.; Weaver, C. 1996: The southern Whidbey Island fault, an active structure in the Puget Lowland. Geological Society of America Bulletin 108. 334-354.

Johnson, S.Y., Mosher, D.C., Dadisman, S.V., Childs, J.R., and Rhea, S.B., 2000. Tertiary and Quaternary structures of the eastern Juan de Fuca Strait: point map, in: Mosher, D.C. and Johnson, S.Y. (Eds.), Rathwell, G.J., Kung, R.B., and Rhea, S.B. (Compilers), Neotectonics of the eastern Juan de Fuca Strait; a digital geological and geophysical atlas. Geological Survey of Canada Open File Report 3931.

Lippman, P.W., and Mullineaux, D.R. editors. 1981. The 1980 Eruptions of Mount St. Helens, Washington. United States Geological Survey Professional Paper 1250.

McCrumb, D.R., Galster, R.W., West, D.O., Crosson, R.S., Ludwin, R.S., Hancock, W.E., and Mann, L.V. 1989. Tectonics, Seismicity, and Engineering Seismology in Washington. Engineering Geology in Washington. Washington division of Geology and Earth Resources. Bulletin 73.

National Geophysical Data Center. November 2001. `http://www.ngdc.noaa.gov/`

Newcomb, R.C., Sceva, J.E., and Stromme, O. 1949. Ground-Water Resources of Western Whatcom County. United States Geologic Survey.

Pringler, P.T. 1994. Volcanic Hazards in Washington – A Growth Management Perspective. Washington Geology. Volume 22, No. 2. pp. 25-32.

Satake, K.; Shimazaki, K.; Tsuji, Y.; Ueda, K. 1996: Time and size of a giant earthquake in Cascadia inferred form Japanese tsunami records of January 1700. Nature 379. 246-249.

Shannon & Wilson, Inc. 1999. Geotechnical Data Report North Cherry Point Substation Project. Prepared for Arco Products Company. Cherry Point Refinery. Ferndale, Washington.

Uniform Building Code (UBC). 1997. International Conference of Building Officials.

USGS. November 2001. Geologic Hazards Web Site: http://geohazards.cr.usgs.gov/eq/

USGS. October 2001. Earthquake Catalogs for 1973-Oct.2001. USGS Web Site: http://neic.usgs.gov/.

USGS. October 2001. Significant Worldwide Earthquake Catalog. USGS Web Site: http://neic.usgs.gov/.

USGS. 1994. USGS Quadrangles for "Blaine"(revised 1994); "Birch Point"(revised 1994); and "Lummi Bay"(revised 1972), Washington.

Waitt, R.B., Mastin, L.G., and Beget, J.E. 1995. Volcanic Hazard Zonation for Glacier Peak Volcano, Washington. United States Geological Survey Open File Report. pp. 95-499.

Walsh, T.J., Gerstel, W.J., Pringle, P.T., and Palmer, S.P. 2001. Earthquakes in Washington State. Washington Geology. Volume 28, No. 3. pp. 22-23.

Washington State Department of Natural Resources. 2000. 100,000-Scale GIS Digital Geology of Washington State. Prepared by Harris, C. and revised by Schuster, J. Olympia, Washington.

FIGURES

ATTACHMENT A

WATER WELL LOGS

ATTACHMENT B

BP CHERRY POINT
MONITORING WELL LOGS

ATTACHMENT C

GEOTECHNICAL SOIL BORING LOGS